

Controlled-release fertilizer(CRF): A green fertilizer for controlling non-point contamination in agriculture

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Abstract: Fertilizers contribute greatly to high yields but also result in environmental non-point contamination, including the emission of greenhouse gas(N_2O) and eutrophication of water bodies. How to solve this problem has become a serious challenge, especially for China as its high ecological pressure. Controlled-release fertilizer(CRF) has been developed to minimize the contamination while keeping high yield and has become a green fertilizer for agriculture. Several CRFs made with special coating technology were used for testing the fertilizer effects in yield and environment through pot experiment and field trial. The result indicated that the CRFs had higher N use efficiency, thus reducing N loss through leaching and volatilization while keeping higher yields. Comparing with imported standard CRFs, the test on CRFs showed similar fertilizer effect but with much lower cost. CRFs application is becoming a new approach for minimizing non-point contamination in agriculture.

Keywords: controlled-release fertilizer; N use efficiency; non-point contamination

Introduction

Intensive input of chemical fertilizers is one of the important characteristics of modern agriculture. China is a developing country with agriculture being one of the most important sectors, fertilizer application in China increased 2.2 times from 1.269 million(nutrient) in 1980 to 4.085 million(nutrient) in 1998(Li, 1998), but the fertilizer amount has still not been enough(Li, 2001). Chinese agriculture is facing such a difficulty that the limited cultivated land must provide more foods and industry raw material because of the increasing population in 21 century. Therefore the food much more depend on fertilizer than before. However, the high application and low use efficiency of chemical fertilizer cause not only income decrease and resources wasting, but also brought about environment pollution resulted from agricultural non-point contamination. The eutrophication in some lakes such as Dianchi, Chaohu, Taihu, Pearl River has been highly concerned by the central and local governments. The green house gas(N_2O , CH_4) released from farmland have drawn international concerns. The problem of non-point pollution in agriculture can not be solved by measures of closing, stopping, removing that have been used for industry pollution. It is necessary for peasants to improve their fertilizer application techniques, but it takes too long a time to solve such an urgent problem. Developing new fertilizer with high use efficiency is then proposed as it can obtain high yield while decrease pollution from nutrient loss. CRFs is such a kind of new fertilizer for high yield and low contamination, thus is a green fertilizer(Liao, 2001). In this paper, several CRFs made in our lab with the special coating technology were tested to evaluate the controlled release characteristics, yield respond and pollution minimizing effect. The prospect of non-point contamination control though fertilizer application is discussed.

1 Materials and methods

1.1 Coated urea PRU and FSU preparing

Coated materials and fertilizers in experimental; PR and FS were inorganic mineral powders, liquid J was paste like high polymer, big grain urea(46% N).

Preparation methods; PR and FS were pulverized to particles passing 0.08 mm mesh, the proportion of solid powder/liquid J/urea was 0.406:0.04:0.554. First, urea and some liquid J were mixed, then 20%—50% of solid power were put in and swing in a disc. Again some liquid J was added to the urea and mixed well, then solid powder was put gradually into the rolling disc until about 85% powder coated around the urea surface. Repeated the addition of liquid J and powder for several times until the entire two components well coated on the urea surface. After a while the coated urea became hard enough and the CRF samples, PRU and FSU, were made.

1.2 Test of leaching characteristic of CRF in soil

Test fertilizers: The two coated ureas(PRU, FSU) containing the

same 25.5% N, plastics coated urea BJU made in Xinhui County, containing 41% N, polymer coated compound fertilizer Osmocote, made in Holland containing $N-P_2O_5-K_2O$ of 14-14-14.

Test soil: It is a red soil derived from granite (Wushan, Guangzhou), with a pH of 5.01, organic matter of 12.2 g/kg, and with a texture. The soil total N, P_2O_5 and K_2O were 0.410, 0.144 and 4.41 g/kg, respectively. The available N, P_2O_5 and K_2O were 49.0, 6.7 and 33.5 mg/kg, respectively. The analytical methods referred to reference(Soil Science Society of China, 1999).

Test methods: Based on the method used by Paramasivam (Paramasivam, 1997), the leaching apparatus used is shown in Fig. 1. A 0.04 mm mesh filter cloth was used to seal the bottom of the plastic tube with a diameter of 5 cm, height of 30 cm, a layer of sand(25 g) was laid on the filter cloth, 250 g(about 10 cm height) air dried soil, passed 2 mm mesh and with 1.3 g/cm³ density similar to plowder layer, was loaded on the sand, then 250 g mixture of soil and fertilizer(same density) was loaded in, a little of sand laid on the surface of soil column for avoiding disturbance of the soil when watering. For every treatment, the N fertilizer rate was the same as 1 g/kg soil. No-fertilizer soil column was set as a control, three replicates for each treatment. First, 150 ml water was added for soil moisture saturation. Secondly, 100 ml water was added for soil column leaching, then the leachate was collected in 24 h. The top hole was sealed with a plastic membrane with little holes after leaching finished for reducing evaporation, then cultured for three days at 35°C in a culturing box. 100 ml water was added for secondary leaching, later operations were the same as above, the total N of each leachate was analyzed with potassium peroxydisulfate oxidation—ultraviolet spectrophotometric method(Soil Science Society of China, 1999).

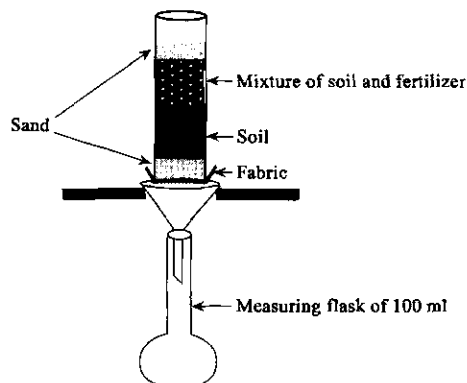


Fig. 1 Schematic plan of soil leaching

1.3 Simulation experiments for NH_3 volatilizing of CRF in soil

Test coated ureas: PRU, BJU and ordinary urea, were the same as

mentioned above.

Test soil: Sample took from garden mould of the university farm, with pH 5.92, OM 37.3 g/kg, total N, P₂O₅ and K₂O were 1.90, 2.30 and 27.10 g/kg, respectively, available N, P₂O₅ and K₂O were 100.36, 66.18 and 107.44 mg/kg.

Test method: "Static Absorption Method" (Ling, 1999) was used for testing NH₃ volatilization. Three treatments were set and three replications for each treatment. 500 g soil was used for each replication. As Fig. 2 shown, 250 g soil was added into a 1000 ml volume glass bottle, followed by 70 ml water adding. The remained 250 g soil and fertilizer were mixed and put into the bottle and followed by 60 ml water adding. For every treatment, the N fertilizer rate was the same as 600 mg/kg soil. In the bottle, a 10 ml small weighing bottle with 2% H₃BO₃ indicator liquid was put on the soil surface and then sealed the 1000 ml bottle mouth for culturing under room temperature. After certain time took the 10 ml bottle out and titrated the NH₃ absorbed with H₂SO₄, after each titration renewed the H₃BO₃ indicator.

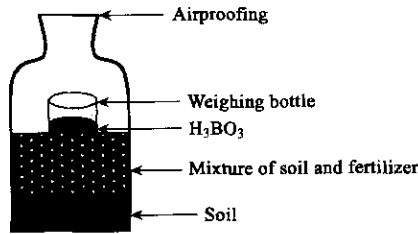


Fig. 2 Schematic plan of NH₃ volatilizing

1.4 Pot experiment

Test fertilizers: In addition to the same fertilizers as 1.1.

Table 1 Pot experiment of rice with different N fertilizer treatments

Treatment	N fertilizer variety	g/pot	Superphosphate, g/pot	Potassium chloride, g/pot	Application, mg/kg(N-P ₂ O ₅ -K ₂ O)
CK0	—	—	5	1.25	0-120-150
CK1	Urea(equal weight)	2.941	5	1.25	270-120-150
CK2	Urea(equal N)	1.63	5	1.25	150-120-150
T1	Coated urea PRU	2.941	5	1.25	150-120-150
T2	Coated urea FSU	2.941	5	1.25	150-120-150
T3	Coated urea BJU	1.786	5	1.25	150-120-150

1.5 Field trial

Test fertilizers, soil and crops were the same as 1.4 and the treatments set up as shown in Table 2.

Test method: 5 treatments(Table 2) were set up for field trial, 3 replicates for each treatment. The plot area was 7.5 m², with a

Table 2 Field trial of rice with different N fertilizer treatments

Treatment	N fertilizer variety	g/plot	Superphosphate, g/plot	Potassium chloride, g/plot	Application, kg/hm ² (N-P ₂ O ₅ -K ₂ O)
CK0	—	—	—	—	—
CK1A	Urea(equal weight)	293.5	600	200	180-90-150
CK1B	Urea(equal N)	529.4	600	200	324-90-150
T1	Coated urea PRU	529.4	600	200	180-90-150
T3	Coated urea BJU	321.4	600	200	180-90-150

Superphosphate (12% P₂O₅), potassium chloride (60% K₂O) and ordinary urea(46% N) were also used.

Test crop: Rice(variety Taisheng 1), growing period were 120 d, provided by the Academy of Agriculture Science of Guangdong Province.

Test soil: Paddy soil from the university farm, pH: 6.02, organic matter; 22.9 g/kg, total N, P₂O₅ and K₂O were 1.36 g/kg, 0.51 g/kg and 5.20 g/kg respectively, available N, P₂O₅ and K₂O were 76.0 mg/kg, 42.3 mg/kg and 63.3 mg/kg respectively.

Test method: As Table 1 shown, 6 treatments were set up with 4 replicates, 5 kg air dried soil was loaded in a pot, all of N, P and K were applied as basal application. All six treatments had the same P and K. The three CRF treatments of the same N, P and K rate could compared with CK2 under equal N rate condition for studying N use efficiency and CK1 was set for the N use efficiency comparison under equal weight(lower N for CRFs) conditions. The soil was put in the pots on 16 April 2001, with two days flooding, then transplanted rice seedlings on 18 April, three plants per pot, harvested on 17 July, 90 d growing period. The yield of biomass and N content of rice were measured.

The plug at the pot side were removed in certain time interval to collect leachate up to 400 ml and N content was analyzed with potassium peroxydisulfate oxidation—ultraviolet spectrophotometric method (Soil Science Society of China, 1999).

The grains and the straw were crushed, digested with H₂SO₄ and H₂O₂, total N was measured by micro-Kjeldahl procedure; the total N content of leachate was measured by the same method (Soil Science Society of China, 1999).

The NH₄⁺-N and NO₃⁻-N of pot soil were measured after harvested. 10 g air-dry sample were extracted with 50 ml of 1 mol/L KCl for 0.5 h, NH₄⁺-N and NO₃⁻-N in the extract were measured by spectrophotometry(Soil Science Society of China, 1999).

randomized block design. All of N, P and K fertilizers were applied as basal application. Rice transplantation on 15 April 2001 and harvesting on 21 July, then the biomass was weighted and N content of the grains and straw were crushed, digested and analyzed as 1.4 indicated.

2 Results and discussion

2.1 Nitrogen leaching characteristics of four CRFs in soil

Fig.3 indicates the N leaching rate of FSU was the highest, reaching 6.31% at first day, about 3 times than others, the leaching rate fluctuated greatly during the test process. The N leaching rate of Osmocote increased evenly within 25 d and became higher than BJU and PRU after 9 d till the end of the testing. The time of maximum N leaching rate occurred for 4 fertilizers, FSU, PRU, Osmocote and BJU, were day 13, 21, 21 and 25 respectively. The N releasing characteristics of PRU in soil were very close to the BJU.

The N releasing rate of Osmocote was slower than PRU at first 5 d, but afterwards, it was clearly faster. The differences of these two CRFs might be due to their different membranes and therefore nutrient release mechanisms(Kochba, 1990).

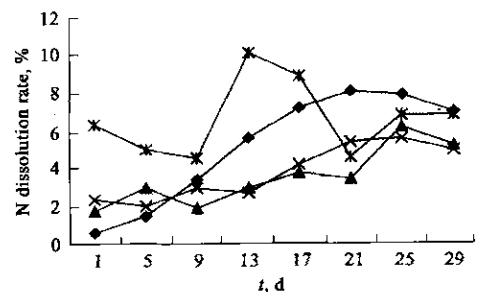


Fig. 3 The N leaching rate curves of CRFs in soil
 ◆ Osmocote; ▲ BJU; × PRU; ■ FSU

Soil leaching and water dissolution were two main methods for testing nutrient release characteristics of coated CRF. As its homogeneous medium-water, the method of water dissolution could not indicate the release rate in soil and, more important, the soil nutrient duration(Xu, 2000; Du, 2002). Shaviv(Shaviv, 1996) suggested that the time for dissolution of 80% N of CRF in water provided information not enough for evaluating the effect of N regulation. The two methods for measuring release rate in water and in soil should be combined for a better evaluation. In this paper, the N leaching rate in soil was measured and found valuable in understanding the relationship of CRFs and the yields.

2.2 NH₃ volatilization of controlling-release fertilizer in soil

NH₃ loss due to volatilization of ordinary urea in soil can be as high as 30% (Li, 1981). NH₃ loss causes not only N use efficiency decrease but also air pollution from green house gas like N₂O, which might also derive from NH₃ oxidation.

Fig.4 indicates that in the whole experiment process, ordinary urea had much higher NH₃ volatilization than the two coated ureas for first 5 d. BJU had very low NH₃ volatilization while PRU was relative higher, but later on NH₃ volatilization of BJU increase while PRU decrease, crossing at day 13. Afterwards NH₃ volatilization of BJU became higher than PRU, and was gradually very close at the end. The total NH₃ volatilization of the three ureas during the whole experiment period of 30 d were: Urea 7.60 mg, PRU 4.37 mg and BJU 4.70 mg. Compared to urea, PRU and BJU reduced NH₃ volatilization by 42.5% and 38.2% respectively.

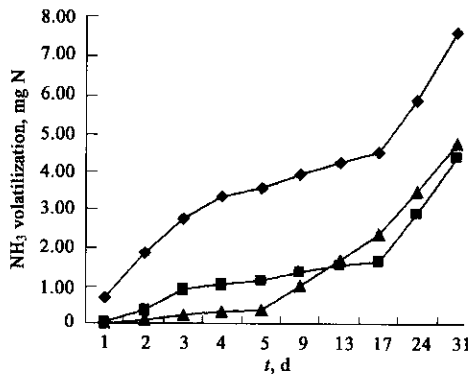


Fig.4 The accumulated value of NH₃ volatilization
 ◆ urea; ■ PRU; ◆ BJU

Under the same conditions of soil urease activity and soil moisture, amount of NH₃ volatilization depends on urea content in soil solution. As urea release slowed down by controlling of the coated ureas, the NH₃ volatilization loss was minimized.

2.3 Pot experiment

2.3.1 The N leaching loss of pot rice

Fig.5 shows the main N leaching loss of all treatments occurred during first three times, these losses of two ordinary ureas(CK1, CK2) were 74.75% and 79.66% respectively. Specially for the first leaching (first three days).

The losses of two ordinary ureas(CK1, CK2) were the highest, indicating a high loss trend of ordinary ureas because of high dissolved rate. The nitrogen leaching loss of three coated urea was lower at early stage, but was a little higher later, indicating a durable, better nutrient supply.

2.3.2 The biomass, grain yield and N utilization efficiency of pot experiment

Among all the five fertilizer treatments, PRU had the highest biomass while CK2(equal N) was the lowest(Table 3), BJU and FSU had lower biomass than PRU because that BJU coating was too tight to release enough N at early stage and FSU coating was not tight enough for slowing down N releasing. It is observed that the BJU leaf showed the light green color and slow tillering at tillering stage, indicating a slightly N supplying deficiency.

For grain yield, the three coated urea treatments were obviously higher than CK2(equal N) with an increase of 15.07%—8.40%. The yield of FSU was the highest among the 3 coated CRFs, quite close to

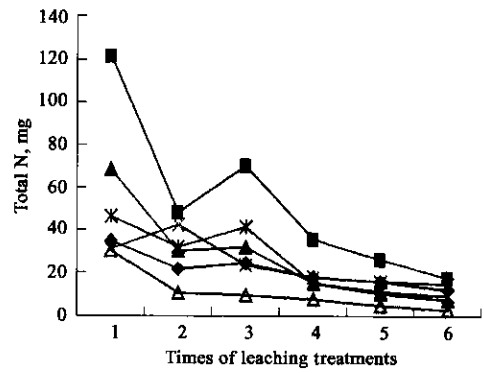


Fig.5 The N loss leaching curves of pot culture
 △ CK0; ■ CK1; ▲ CK2; × T1; * T2; ◆ T3

CK1(equal weight). FSU had a relative faster leaching rate in soil, but showed a better yield, indicating that fertilizer effect can not be evaluated only according to N leaching rate. In addition to CRF, crop variety and weather (rain and temperature) conditions were also very important factors for fertilizer effect of CRFs.

Table 3 The biomass, grain yield and N use efficiency in pot experiment

Treatment	Biomass, g/pot	Grain yield, g/pot	N use efficiency, %
CK0: Blank check	66.45 ^a	31.08 ^c	
CK1: Urea(equal weight)	88.37 ^{ab}	39.78 ^a	30.25 ^d
CK2: Urea(equal N)	72.53 ^d	34.03 ^d	42.81 ^c
T1: Coated urea PRU	89.66 ^a	37.70 ^{bc}	69.87 ^a
T2: Coated urea FSU	85.45 ^{bc}	39.16 ^{ab}	62.75 ^a
T3: Coated urea BJU	83.55 ^c	36.89 ^c	59.34 ^b

Notes: SSR was used for data multiple comparison, mean values within a column followed by the same letters are not significantly different(P = 0.05)

The N use efficiency of all the three coated ureas reached 59% and up, much higher than the ordinary urea(CK1, CK2), the percentage point increase were as high as 17—30.

2.3.3 The residual N in soil after rice harvesting

There were obvious differences of soil NH₄⁺ and NO₃⁻ between three coated CRFs and three CKs. The coated CRFs had higher N than CK2 (equal N). T2 and T3 were even a little higher than CK1, a higher N treatment. BJU was the highest among six treatments because of the highly tight coating, which led to relative low N release and thus relative low biomass and yield. The higher residual N in soil of coated CRFs suggested that the higher yields could be obtained through CRF application without decreasing soil N as the higher N use efficiency of CRFs.

Table 4 The residual NH₄⁺-N and NO₃⁻-N in soil after rice harvesting, mg/kg

Treatment	NO ₃ ⁻ -N	NH ₄ ⁺ -N	NH ₄ ⁺ -N + NO ₃ ⁻ -N
CK0: Blank check	10.29 ^c	11.49 ^c	21.78 ^c
CK1: Urea(equal weight)	11.01 ^b	13.35 ^b	24.36 ^b
CK2: Urea(equal N)	11.05 ^b	13.62 ^b	23.67 ^b
T1: Coated urea PRU	11.49 ^b	12.62 ^b	24.11 ^b
T2: Coated urea FSU	11.06 ^b	13.42 ^b	24.48 ^b
T3: Coated urea BJU	12.72 ^a	17.13 ^a	32.85 ^a

Notes: SSR was used for data multiple comparison, mean values within a column followed by the same letters are not significantly different (P = 0.05)

2.4 Field trial

2.4.1 The biomass, yield and N utilization efficiency in field

Table 5 shows that the biomass of the two coated ureas treatments were higher significantly than ordinary ureas(equal N, equal weight). The biomass of BJU was lower significantly than PRU. It is shown that the proper nutrient release rate was important for the high yield, and too high or too low rate was negative to fertilizer effect and N use efficiency.

Table 5 The biomass, grain yield and N use efficiency in the field

Treatment	Biomass, kg/hm ²	Grain yield, kg/hm ²	N use efficiency, %
CK0: Blank check	5.13 × 10 ³ ^d	3.31 × 10 ³ ^b	—
CK1: Urea(equal weight)	9.27 × 10 ³ ^{bc}	5.60 × 10 ³ ^a	16.93 ^d
CK2: Urea(equal N)	8.91 × 10 ³ ^e	5.20 × 10 ³ ^a	28.20 ^c
T1: Coated urea PRU	10.92 × 10 ³ ^a	5.64 × 10 ³ ^a	56.63 ^a
T3: Coated urea BJU	9.89 × 10 ³ ^b	5.27 × 10 ³ ^a	46.05 ^b

Note: SSR was used for data multiple comparison, mean values within a column followed by the same letters are not significantly different ($P = 0.05$)

Under field conditions, the fertilizer nutrient loss was higher than the pot experiment due to heavy rain, but coated CRFs could still increase yield while reduce nutrient loss.

The N use efficiency of the two coated ureas were higher significantly than the two ordinary ureas, with an increase of 18–28 percentage point, about 50%–100% increase. The four fertilizer treatments showed significant differences in N use efficiency but no significant differences in yields, because the heavy rain and poor drainage leading to excess N supplying. It resulted in dark green leaf and poor grain filling. This indicated that yield related to not only fertilizer but also proper field management.

2.4.2 Residual N in soil after rice harvesting

Table 6 indicates that NO₃⁻-N of all the treatments had no significant differences, but NH₄⁺-N and mineral N of the two coated ureas were significantly higher than ordinary urea, the highest was BJU, with a tight coating and thus a slow N releasing. The analytical data indicated that the coated ureas had stronger nutrient holding capacity than ordinary ureas, keeping more nutrient in soil. The high yield can be obtained by properly controlling nutrient release velocity of the fertilizer, which increased N use efficiency and thus decreased nutrient loss for remaining more nutrient in soil.

Table 6 The residual NH₄⁺-N and NO₃⁻-N in soil after rice harvesting, mg/kg

Treatment	NO ₃ ⁻ -N	NH ₄ ⁺ -N	NH ₄ ⁺ -N + NO ₃ ⁻ -N
CK0: Blank check	8.34 ^a	15.33 ^d	23.67 ^d
CK1: Urea(equal N)	8.73 ^a	16.53 ^{cd}	25.26 ^{cd}
CK2: Urea(equal weight)	9.04 ^a	18.30 ^c	27.34 ^c
T1: Coated urea PRU	8.83 ^a	23.17 ^b	32.00 ^b
T3: Coated urea BJU	8.86 ^a	26.00 ^a	34.86 ^a

Notes: SSR was used for data multiple comparison, mean values within a column followed by the same letters are not significantly different ($P = 0.05$)

2.5 Fertilization for contamination control

Based on this research, it is found that CRFs could slow down its N release at early stages and remain higher N supplying capacity at later stages. Therefore, a model of “peak cutting for valley filling” (Fig. 6) has been formed to reduce excess N supplying at early stage and avoid N deficiency at later stage. Such a N supplying model could increase N use efficiency greatly, resulting in high yield and low risk of pollution.

The production of CRF has been produced for more than 40 years, but the consumed quantity was only about 0.15% of the total chemical fertilizer quantity until the end of 20 century (Martin, 1999). The main reasons are high costs of controlled release material, equipment and complex processing techniques.

In order to find out an approach for CRF production suitable to Chinese agriculture, some cheap coating materials, ordinary equipment and relative simple processing techniques have been developed. The

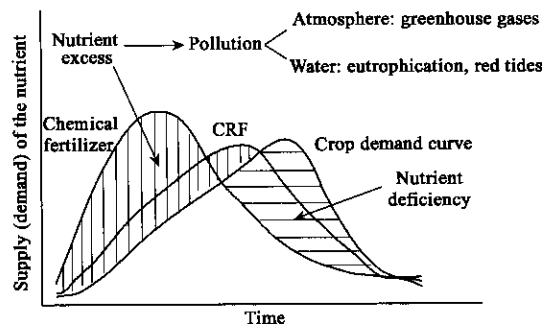


Fig. 6 CRF model of “peak cutting for valley filling”

present research indicated the CRFs produced by new technique have some satisfactory results in the yield, N use efficiency and pollution control. It is necessary and also possible for CRFs enter broad agricultural land. CRF application is not only a measure for high yield but also a new approach of “fertilization for contamination control” which is of important environmental significances and wide marketing prospective. It has shown obvious advantages: Firstly, highly effective, it can save about 30% fertilizer, thus reducing nutrient loss while maintaining high yield. Secondly, low cost. The cost for fertilizer could be also beneficial to environment without extra expenses. Third, wide application for all farmland and crops. This approach is to solve the problem focusing on its cause at beginning, not focusing on its results at the end, and is worthy further studying.

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